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The effect of an external audio signed on vigilance performance and physiological parameters.

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http://hdl.handle.net/10945/14971

THE EFFECT OF AN EXTERNAL AUDIO SIGNAL
ON
VIGILANCE PERFORMANCE
AND
PHYSIOLOGICAL PARAMETERS

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THESIS

THE EFFECT OF AN EXTERNAL AUDIO SIGNAL
ON
VIGILANCE PERFORMANCE
AND
PHYSIOLOGICAL PARAMETERS

by

William Stanley Marshall III

April 1970

The Effect of an External Audio Signal
on
Vigilance Performance and Physiological Parameters

by

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
April   1970

ABSTRACT

This research was performed to determine the effect of an external
audio signal on visual monitoring performance and any associated
changes in physiological parameters of the subjects. The number of
correct detections, the number of commissive errors, skin temperature,
and skin resistance were recorded throughout the experiment. A two
way nested analysis of variance showed that the application of the audio
signal did not have a significant effect on the vigilance decrement.
The same type of analysis was used to show that the audio signal did
not have a significant effect on the physiological parameters measured
in the experimental group. Over all experimental groups, skin resist-
ance and skin temperature did change, but the changes were not unique
to any given experimental condition. Multiple correlation analyses
of the data indicated a high degree of complex interaction between the
physiological parameters measured and the vigilance detection decrement.

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I. INTRODUCTION

One of the basic requirements for productivity in the present
times is the adoption of various types of machinery to perform tasks
hitherto performed by man. This trend is evident in both military and
industrial operations; and is not restricted to any particular nation or
society. A by-product of this evolution towards automation has been
the requirement for man to monitor the operation and/or the output of
a system. This new requirement for man has resulted in the observ-
ance of a definite decrement in the ability to effectively perform
monitoring tasks of a routine nature. One of the first extensive studies
of this monitoring decrement was performed by Mackworth (1950). In
his study, Mackworth introduced the term "vigilance" to refer to an
observer's readiness to detect infrequent, aperiodic, small changes
in the environment.

There are many situations in modern life which encompass
vigilance situations. A common example which most people have
experienced is the requirement to watch the road on a long driving
trip. This example illustrates the requirement for an observer, the
driver, to be ready to detect any infrequent, aperiodic, small change
in the environment, such as the acceleration or deceleration of vehicles
in the proximity. Additional examples include the observation of items
in an assembly line for defects, monitoring automated equipment for
defects, listening to sonar signals for significant targets and scanning

radar scopes for aircraft or ships in the vicinity. Jerison and Pickett (1963) refer to the human factors problem of the vigilance decrement as related to the space missions. Weight restrictions and design delays often prohibit the use of electrical or mechanical monitoring systems aboard the spacecraft. As a result, many of the monitoring tasks must, through necessity, be performed by man. Failure to accurately detect and interpret the signals displayed could produce catastrophic results.

As a result of the great number of monitoring tasks which exist, and the importance of man being able to accurately perform these tasks, there have been a multitude of studies in the area of the decrement associated with monitoring tasks. Due to the large number of studies conducted, and the many different independent and dependent variables which have been investigated, it is impractical to reference all work done to date in this field. However, a few of the important studies which are relevant to this paper will be discussed to provide a background to the objective.

II. BACKGROUND

The impetus for Mackworth's (1950) study of the vigilance decrement was the poor performance of British aircraft radar operators during World War II. Mackworth found that there is a definite decrement in the ability of subjects to detect signals in a visual monitoring situation after a period of thirty minutes. He found this decrement could be decreased by providing feedback of results to the subject, by providing benzedrine or an equivalent stimulant to the subject, and of course by changing the subject at the end of a thirty minute period. In most practical situations the above procedures cannot be applied. For example, if an observer fails to detect a defective item on an assembly line, it may be months, if ever, before the omissive error is detected. The adverse physiological effects of stimulants prohibit their being used over an extended period of time; and excessive cost and manpower requirements many times prohibit the replacement of a monitor or observer after thirty minutes of work.

An additional phenomenon associated with the vigilance decrement is that subjects vary considerably in their ability to perform monitoring tasks. This variance among subjects is considered a phenomenon due to the fact that the cause of variance among subjects cannot be substantiated. Mackworth (1950) noted that his subjects differed in their ability to perform the monitoring tasks assigned; and that the cause for this difference was unknown. He tested the subjects and determined

that the differences were not due to visual acuity or intelligence test scores as might be expected. Jerison and Pickett (1963) endeavored to determine predictive indicators that might enable one to select good radar or sonar operators. No significant correlations were found to exist between vigilance performance and standard psychological tests. They concluded that vigilance performance is highly variable between people; and that no satisfactory analysis of the sources of variation were evident at that time.

There have been several theories advanced to account for monitoring performance in the various vigilance situations. Mackworth (1950) noted that there is some central process in the brain that is responsible for watchfullness.

Hebb (1955) advanced the idea of an "arousal" system with motivational properties in the brain stem. This system may be considered as a second major pathway by which all sensory excitations reach the cortex. (In addition, there is feedback from the cortex.) This second pathway serves to tone up the cortex with background supporting action. This "tone up" is necessary for messages from sensory nerve, to sensory tract, to the sensory nucleus of the thalamus to have their proper effect. The sensory event which is responsible for guiding behavior or controlling goal responses is referred to as the "cue function". The Arousal Theory asserts that without a sufficient foundation of arousal (or vigilance function), the cue function cannot exist. Increasing the level of the arousal stimuli will strengthen or

maintain cortical activity. However, when arousal is at a high level, increasing the activity may interfere with the cue function by facilitating irrelevant responses. Thus, when the arousal function is at a low level, an increase may be rewarding and strengthen cortical activity; whereas at high levels it is a decrease that rewards.

Frankmann and Adams (1962) reviewed the Attention Theory of Broadbent. This theory attributes the vigilance decrement to a decrease in novelty of the critical signal caused by the repeated applications of the particular stimulus; and the resulting ascendency of competing stimuli in the vigilance situation. The Attention Theory advocates the introduction of a new stimulus between applications of the original stimulus; since this introduction will temporarily renew the novelty of the original critical signal stimulus.

Wiener (1964) observed that multiple source tasks usually do not involve a time decrement whereas single source tasks do. He conducted an experiment to investigate the effects of channel load in a one, two, and three meter vigilance task. The number of stimulus channels (the number of voltmeters) were the independent variable in the experiment. The number of omissive and commissive errors were recorded for the 42 subjects involved in the experiment. The results showed that the time decrement existed for all subjects irregardless of whether they were viewing one, two, or three meters during the experi-ment. The number of omissive errors recorded for the subjects viewing two and three meters was essentially the same; but considerably greater

than the number recorded for subjects required to view only one volt-meter. Thus, it is apparent that increasing the channel load is not a solution to the vigilance decrement.

Numerous experiments and studies have been conducted to decrease the vigilance decrement by providing external audio stimuli during a monitoring task to improve the vigilance decrement. This approach supports the Attention Theory. It should be noted however, that even before the Attention Theory was postulated by Broadbent in 1953, the importance of external audio stimuli was observed. Mackworth (1950) informed one group of his subjects that during their vigilance task they would receive a phone call. The call was made to the subjects one hour after the two hour task had commenced. It was found that the subjects' anticipation of the phone call decreased their accuracy slightly during the first hour. However, the accuracy observed after the phone call was comparable to that initially observed in the fresh subjects. This increase in efficiency lasted 35 minutes.

Broadbent (1957) conducted an experiment to determine the effect of noise of varying frequency and intensity on the ability of subjects to perform prolonged tasks requiring unremitting attention. The number of correct responses by the subjects showed no effects from the noise. However, the number of errors was found to be significantly higher when high frequency noise of a high intensity was presented. Thus, a general lowering of efficiency was induced by noise of a high frequency and intensity.

Poock and Wiener (1966) investigated the effects of the application of background music during the monitoring task. Seventy-five subjects were assigned randomly into one of five equal groups. Each group was subjected to either preferred music, non-preferred music, white noise, a conversation between airport tower controllers and pilots (T group), or given an opportunity to choose one of the preceding four backgrounds (choice group), at any time during the vigilance task. (The selection of music as preferred or non-preferred was based on a survey of students from the same population as the subjects in the experiment.) Results of the experiment showed that pairwise differences in the percentage of signals detected among the five audio background groups was significant between the T group and all others except the non-preferred music group. No other pairwise differences were significant. The superior performance of the T group is contrary to any intuitive hypothesis, and could not be explained by the authors. The audio background had no significant effect on the number of commissive errors.

Randel (1968) investigated the effect of the presentation of a signal in the form of a 1000 cps tone, twenty db above threshold, for one second, during a one hour visual monitoring task. The hypothesis was that the introduction of the audio signals would serve to restore an optimum arousal level. Subjects were divided into three groups. One group received no audio signals. A second group received a "ready" audio signal just prior to the visual signal; and the third group received random audio signals separated by either 1, 2, 4, 5, or 7 minutes.

The first group, subjects that received no audio signal, exhibited the familiar time decrement in performance. The second group, the ready-signal group, indicated stable performance throughout the vigilance task. This was expected since the group was forewarned of the visual signal. The third group, comprised of those subjects that received random audio signals, exhibited a vigilance decrement. However, this decrement was sufficiently different from the first group to indicate that the vigilance decrement had been attenuated to a significant degree. The results of these studies indicate that there is a definite correlation between the vigilance decrement and background audio stimuli. Both the Arousal Theory and the Attention Theory were supported by the results that were attained. At the present time however, insufficient evidence is available to ascertain which of the two theories mentioned above is the most accurate; or which is the predominant theory in describing the vigilance decrement exhibited by man when performing a vigilance task. To improve the vigilance decrement, the measurement of the physiological changes that occur when a subject is engaged in a monitoring task has been the subject of several studies in recent years. The primary purpose of most of these studies has been to accurately ascertain those factors that are contributing to variations in performance. Thus, the concluding portion of this background information will be devoted to investigating a few of the significant studies that have been conducted to measure physiological changes that occur.

Dardano (1962) measured the palmer skin resistance and reaction time of 36 subjects during a three hour vigilance task. The independent variables consisted of three signal programs with varying intersignal intervals, and the application of intermittent wide band noise of varying intensity. The combinations of the two noise conditions and the three levels of intersignal interval variability provided six experimental conditions. Six subjects were randomly assigned to each condition. The results showed that noise only impaired performance when the minimum variance signal schedule was presented. Reaction time was found to be inversely related to the length of the intersignal interval for the minimum and intermediate signal schedules. Basal skin conductance was analyzed and found to be negatively correlated with reaction time for subjects exhibiting an extreme decrement under the schedule with maximum variability of intersignal interval.

Eason, Beardshall and Jaffee (1965) hypothesized that variations in vigilance performance are in part determined by changes in activation level. To test this hypothesis, physiological measures were recorded to reflect changes in the level of activation, arousal, and alertness. Six subjects were assigned one hour vigilance tasks. The only independent variables were a fast (two random signals per minute) and a slow (one random signal every two minutes) rate of critical signal presentation. Skin conductance, heart rate, neck muscle tension level, number of correct detections, and a composite recording of eyelid activity and vertical eye movement were all recorded during the vigilance task.

Analysis of the data revealed that there was a significant decrease in the number of correct detections and skin conductance during the hour vigil; and a significant increase in neck muscle tension level. No significant change in heart rate was observed, and none of the dependent variables changed significantly as a function of the signal presentation rate. Thus, the results of the study supported the null hypothesis established.

Andreassi, Rapisardi, and Whalen (1967) presented fixed interval and variable interval visual signal patterns to four subjects and measured their physiological responses and reaction times. No significant correlation was found to exist between the physiological parameters recorded and the vigilance performance of the subjects. However, it was hypothesized that the lack of significant correlation between reaction time and the physiological measures might have been partly due to a limited range of arousal under the conditions of the experiment.

Tinsley (1969) assigned a vigilance task to six subjects and measured heart rate, skin resistance, blood pressure, skin temperature, and the number of correct responses during a 48 minute vigil. It was found that diastolic blood pressure, skin temperature, and systolic blood pressure were the physiological parameters which showed a significant correlation with vigilance performance. In addition, by using multiple correlational techniques it was found that systolic blood pressure and skin temperature had a high pairwise relationship with detection performance.

III. OBJECTIVE

The background material was presented to show some of the research which has been accomplished to date. The purpose of the present study was to attempt to extend the findings of the reviewed studies.

Eason, Beardshall, and Jaffee (1965) concluded in their study that the measuring of physiological changes is beneficial to the researcher and to applied human factors specialists who are interested in understanding and predicting vigilance performance. Andreassi, Rapisardi, and Whalen (1967) found that the measures are of potential utility in predicting performance in either vigilance training or operational situations. Dardano (1962), Eason, Beardshall, and Jaffee (1965), and Tinsley (1969) observed correlations between physiological parameters measured and the vigilance decrement. Due to the preceding findings and observations, physiological parameters were measured for each subject throughout the vigil.

Poock and Wiener (1966) in their study recommended further investigation of the effects of non-musical backgrounds during a monotonous monitoring task. Broadbent (1957), Poock and Wiener (1966), and Randel (1968) all observed that external audio stimuli have an effect on the vigilance decrement. Therefore, it was decided to use the introduction of an audio stimulus during the vigilance task as an independent variable in this study.

Thus, the objective of the present study was to determine the effect of a particular external audio stimulus, presented at random intervals during the vigil, on the vigilance decrement; and to observe the differences in physiological parameters which occurred when the external audio stimulus was present versus the situation when the visual signal was the only stimulus present. It was anticipated that differences in the physiological parameters recorded would provide additional information on the role of expectancy and arousal during the vigilance situation.

IV. METHOD

The same laboratory and the same major pieces of equipment

that Tinsley (1969) utilized were required for the conduct of the

experiment.

A. EXPERIMENTAL DESIGN

To simulate a vigilance task the subjects were required to

observe a voltmeter which was programmed for sixty normal deflections

per minute. The duration of the vigilance task was 48 minutes. No

smoking or beverages were permitted during the experiment. At random

times a critical signal which consisted of a needle deflection of a

larger magnitude than the normal deflection was presented. The sub-

jects were required to respond to this critical signal by depressing a

button on a switch which was held in their hand. A response within

2.5 seconds of the occurrence of the critical signal was considered to

be a detection. All other responses were considered to be commissive

errors. The occurrence of critical signals and all responses were

recorded throughout the experiment. The length of the vigilance task

was 48 minutes; and each subject was tested individually.

Throughout the experiment an Allied H-885 Headset was worn

by each subject through which white noise at a thirty db level was

heard. This white noise prevented the subject from being alerted by

the entry of anyone into the laboratory, and from hearing the noise

produced by the equipment required for the experiment. The headset also provided the media for the introduction of the external audio signal presented at random times throughout the experiment to the six subjects in the experimental group. This random external audio signal was in the form of a 500 cps tone, at a forty db level, and was presented for a duration of one second while the white noise was interrupted.

A table of random units was entered to extract times for the occurrence of the critical signal of greater magnitude, and the occurrence of the audio signal for the experimental group. There were eight critical signals during each twelve minute period for a total of 32. There were four audio signals during each twelve minute period. The occurrence of the audio signal would have been modified if it had been coincidental with the critical signal; but this modification was not required since the two random schedules did not coincide at any point during the 48 minute task.

Skin temperature and skin resistance were recorded graphically throughout the vigilance task. In addition, a graphical display of the number of correct responses and the number of commissive errors was recorded throughout the experiment.

B.   SUBJECTS

Twelve male military officer graduate students were randomly selected and agreed to serve as subjects to participate in the experiment. The subjects ranged in age from 26 to 36 years of age. An equal

number of the officers selected were Marine Air, Marine Ground, Army Ground, and Navy Surface. The last names were ranked in alphabetical order from one to twelve. The even numbers were assigned to a control group with no external audio stimulus; and the odd numbers were subjected to an external audio stimulus during the vigilance task. Each subject was tested only once to preclude any learning effect during the experiment. None of the subjects had previously performed a similar vigilance task.

C. SEQUENCE OF EVENTS

Fifteen minutes prior to the introduction of each subject into the laboratory the equipment to be utilized was turned on to provide a warm up period and the stabilization of the recording devices. During this time all settings were checked to ensure consistent experimental conditions. When the subject entered the laboratory, his coat, watch, and rings were removed. An inquiry was made to determine if the subject was right or left handed. Right handed subjects held the response switch in their right hand throughout the experiment; and similar action was taken for the left handed subjects. Subjects were then led to a booth constructed for the experiment and seated in a comfortable position with their arms placed on the table. The skin areas where the electrodes and thermistor would be placed were cleaned with Phisohex brand surgical detergent. The detergent was then rinsed from the skin areas, and rubbing alcohol was applied and allowed to dry. The thorough cleaning of the skin areas reduced the skin resistance measurements substantially.

When the skin areas were dry, the electrodes and thermistor were attached to the subject. The pen zero and balance settings for the graphical recording devices were set for the readings being obtained from the subject. This was done to ensure that the proper range for each subject would be available throughout the experiment. The following instructions were then read to each subject:

> You have been selected to participate in a vigilance experiment. During the experiment you will remain seated in a comfortable position. Your task will be to observe the meter to your immediate front. The needle on the meter is programmed for sixty normal deflections per minute. At random and infrequent time intervals a critical signal of a greater magnitude will be observable. When this critical signal appears, you are to respond by depressing the red button on the switch you are holding. You will have to pay close attention to the meter to avoid missing critical signals or responding to normal signals.
>
> Throughout the vigilance task, your skin resistance will be recorded by the two electrodes which have been placed on your palm and forearm. In addition, skin temperature will be recorded via a thermistor which is attached to the palm of your hand opposite the red electrode. As you can see, no uncomfortable sensation or danger is associated with the electrodes and thermistor. You are requested to keep your fingers extended in a natural and comfortable position, and to keep your forearm on the table, facing up, throughout the experiment. In addition, refrain from touching the sensing devices and the surrounding skin areas. A headset will be provided through which white noise at a thirty db level will be heard to eliminate all background noise during the actual run.
>
> I will now give you an opportunity to observe normal and critical needle deflections. This practice run will be under the same conditions as the actual run which will follow with two exceptions. The frequency of critical signals during the actual run will

be much less than that observed in the practice run; and the headset will not be worn for the practice run so you can ask questions. Do you have any questions at this time? Be sure you understand exactly what your required task encompasses; since there will be no opportunity for additional questions once the actual run commences.

After the subject was instructed in his task a practice run of three minutes duration was provided during which eleven critical signals were presented. An inquiry was made to ensure that the subject understood his task. The headset was then applied to the subject and adjusted to a comfortable position. Subjects were instructed not to touch or adjust the headset during the actual run since it was found that the metal on the headset grounded skin resistance readings. An observation was made of the skin resistance and skin temperature recordings available for the subject and the pen zero and balance settings were reset. The pen zero and balance settings could not be changed again until after calibration.

The 48 minute vigilance task was then begun. At the conclusion of the actual run the subject was dismissed and skin temperature and skin resistance were calibrated to obtain the specific values recorded during the subject's vigilance task.

A General Radio Company Decade Resistor, Model 1432-Q, was utilized at the conclusion of each experiment to calibrate each subject's skin resistance. This was accomplished by removing the probes with the electrodes from the console, and inserting probes from the

decade resistor into the console in place of the subject, and varying the resistance of the decade resistor.

Skin temperature was calibrated by placing the thermistor in an oven with a thermometer. A power supply was connected to the oven and the temperature therein increased by adjusting a rheostat control on the oven. The temperature registered by the thermometer was recorded when it was in the range of the subject's skin temperature as indicated by the graphical results of the experiment.

D.   ELECTRODE PLACEMENT AND APPARATUS

To monitor skin resistance a unipolar placement of Beckman Biopotential Skin Electrodes as described by Venables and Martin (1967) was utilized. The active electrode was placed on the volar surface of the hand, one inch from the first joint of the thumb. The reference electrode was placed on the inside surface of the arm, one inch below the radioulnar joint. The electrodes were placed on the arm opposite the hand which held the response switch. Beckman Offner paste was inserted into the electrodes just prior to placement on the skin to improve the contact. The electrodes were held in place by Beckman adhesive paper applicators.

To monitor skin temperature a Yellow Springs 400 Series Thermistor was utilized. The thermistor was placed opposite the active electrode on the volar surface of the hand. This site was chosen due to the large variation in hand temperature as opposed to the relative constant temperature of the forearm. The thermistor was held in place by two Beckman adhesive paper applicators.

Skin temperature and skin resistance were recorded continuously throughout the experiment graphically by using a six pen Edin Company Oscillograph Recorder. The voltage inputs to the recorder pens were produced by circuitry utilizing the electrodes, thermistor, and Brush Electronics Company Dual Channel D.C. Amplifiers. The latter provided the pen zero and balance control which were required for accurate calibration.

E.   APPARATUS

The voltmeter used in the experiment had a four inch by $3\frac{1}{2}$ inch unmarked white viewing area with the glass plate removed to reduce reflections. The voltmeter was mounted in the center of a 40 inch by 24 inch piece of plywood painted white. The plywood was placed on a table so that the voltmeter was in a vertical position, 26 inches from the seated subject, and at a height about six inches below eye level. Paneling was placed around the table and chair on three sides so that when the subject was seated, the voltmeter and response switch were the only objects in view.

The white noise was generated by a Lafayette Instrument Company Model 14315 White Noise Generator. A Hewlett Packard Model 200 C Audio Oscillator was used to produce the external audio signal. A punched paper tape was fed through an Ohrtronics Model 119 Paper Tape Reader to produce an electrical pulse to the voltmeter and produce the signal rate of sixty deflections per minute.

Two potentiometers were used in conjunction with the tape reader to control the deflection of the voltmeter needle. The regular signal traversed an arc of forty degrees, and the critical signal traversed an arc of 46 degrees. Preliminary experimentation showed this six degree difference to be satisfactory in producing a vigilance decrement during pilot trials.

The occurrence of a critical signal provided a pulse to the oscillograph recorder, and caused a mark to be produced by one of the six pens. An adjacent pen recorded each detection response by a subject. These adjacent marks provided a means of analyzing correct detections and commissive errors.

F.   DISCUSSION

Pilot experimentation was conducted with white noise at a twenty db level. The Ohrtronics Paper Tape Reader was by far the most audible piece of equipment utilized in the experiment. An insulated box was constructed which enclosed the tape reader and greatly reduced the operational noise. It was found that enclosing the tape reader caused an increase in operating temperature and a decrease in the signal rate to fifty deflections per minute. As a result the soundproofing was removed; and the white noise increased to a thirty db level.

The subjects were not informed of the specific length of the vigilance task. However, due to the extended time required for preparation, instruction, practice run, and the actual run of the experiment, it was necessary to inform the subjects that about ninety minutes of

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their time would be needed. Thus, the subjects had a general idea of the maximum length of the experiment; but could not keep track of the actual time lapse during the experiment since they had no watches.

The subjects were required to keep the forearm with the electrodes attached in an upright position to prevent changing pressure with the skin areas and the resultant extraneous variation in skin resistance. An additional reason for this requirement was that during the initial testing, a subject placed his arm on his abdomen, and this resulted in an extraneous increase in skin temperature while the arm was in this position.

Systolic and diastolic blood pressure were not measured during the experiment as was done in the experiment conducted by Tinsley (1969). These periodic measurements would provide an extraneous external physical stimulus to each subject throughout the vigilance task.

V. ANALYSIS

A. REDUCTION OF DATA

After all the subjects had been tested, the graphical record of detection performance and physiological measures that had been obtained during the monitoring task were studied. The occurrence of a detected critical signal by the subject did not produce any change in the skin temperature or skin resistance readings. That is, if the subject's skin temperature was decreasing (increasing) prior to the detection of the critical signal, it continued to decrease (increase) at the same rate after the detection of the critical signal.

The data used in the analysis of the performance measures of the subjects was obtained from the graphical output by considering four 12 minute time intervals. For each subject the percentage of correct detections, number of commissive errors, mean skin temperature, and mean skin resistance were obtained for each of the four consecutive time intervals. A graphical representation of the mean value of the percentage of correct detections, mean skin temperature, and mean skin resistance for the control group and the experimental group is depicted in Figures 1, 2, and 3 respectively.

B. RESULTS

The data was analyzed by a two way nested analysis of variance in which the subjects were nested in the control and experimental
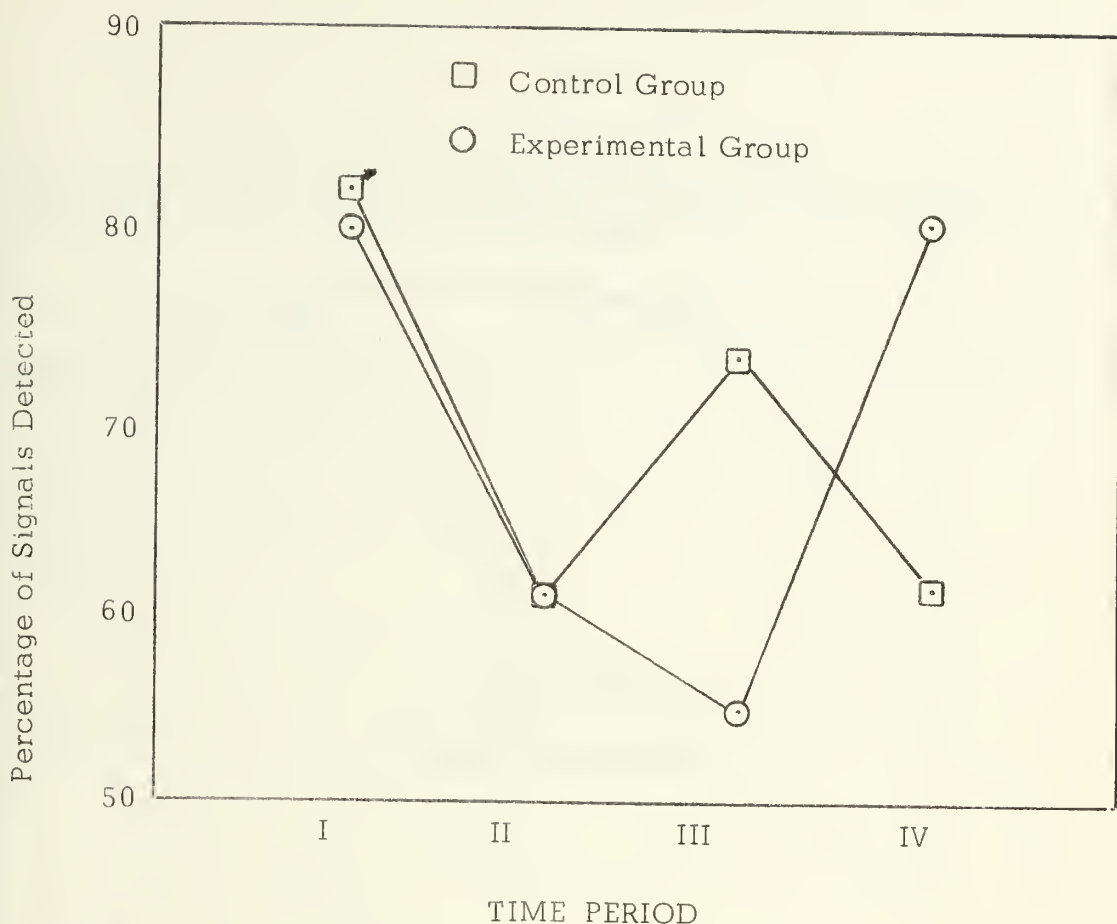
Figure 1. Percentage of signals detected per 12-minute period

conditions with all the subjects common to the same four time intervals.
The nested analysis of variance was performed on each of the three
variables shown in Figures 1, 2, and 3 to test for significant differences
due to the application of the external audio stimulus and between the
four time intervals.

1.   Percentage of Correct Detections

Table I shows the results obtained from a two way nested
analysis of variance on the transformed percentage of correct detections.

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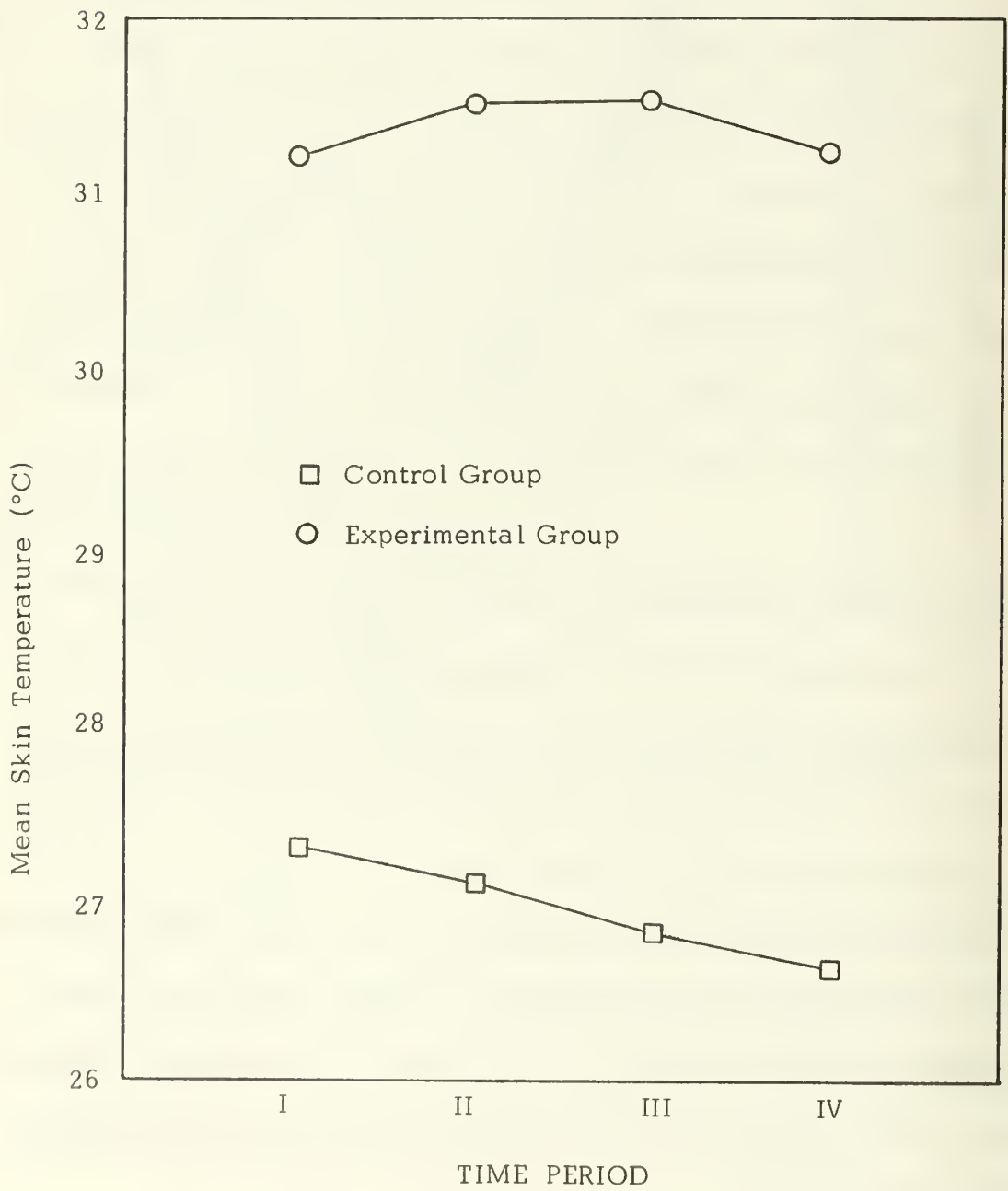
Figure 2. Mean skin temperature per 12-minute period
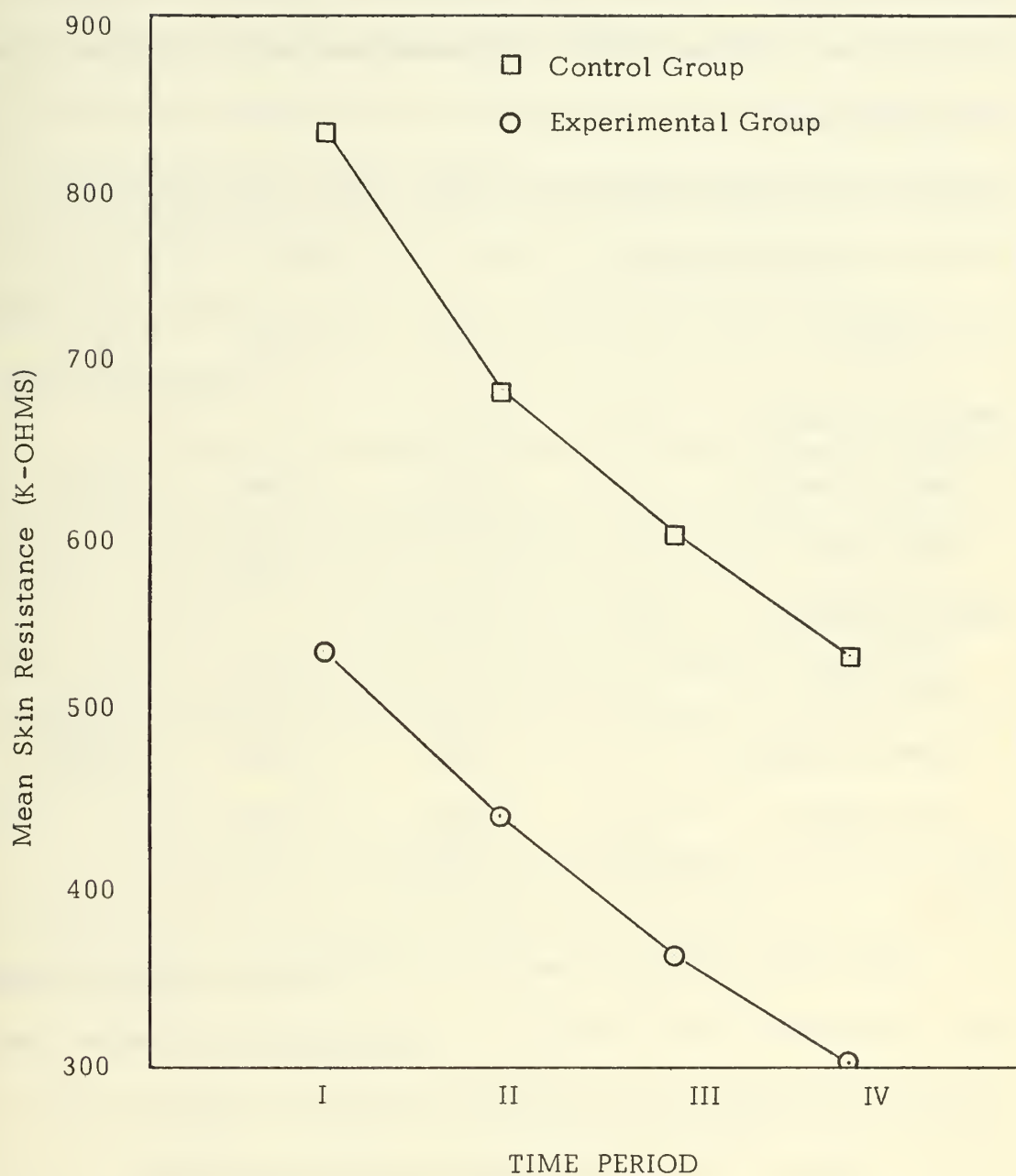
Figure 3.   Mean skin resistance per 12-minute period

Since the data for the percentage of signals detected was a proportion which assumed a maximum value of one, an arcsin transformation was performed on the data prior to performing the analysis of variance as recommended by Winer (1962). This transformation served to stabilize the variances.

Table I. Analysis of variance on the transformed percentage of correct detections

Source	df	SS	MS	F	p
Between Subjects	11	11.517			
Audio Stimulus	1	0.030	0.030	0.026	N.S.
Error (bet.)	10	11.487	1.149		
Within Subjects	36	8.032			
Time Period	3	2.220	0.740	5.089	0.01
Time x Stimulus	3	1.450	0.483	3.324	0.05
Error (with.)	30	4.362	0.1454		
Total	47	19.549			

From Table I it can be seen that the difference in signals detected due to the external audio stimulus was not significant. However, the changes in performance during the four time intervals and the Time x Stimulus interaction were significant at the indicated levels.

To check the possibility that combinations of physiological parameters might collectively be correlated with monitoring performance, a multiple correlation analysis was performed. The transformed percentage of correct detections was treated as the dependent variable with

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skin temperature and skin resistance as the independent variables.

A calculation was made to obtain a multiple correlation coefficient

for the experimental group, the control group, and the combined groups.

Skin resistance values were not available for four of the subjects.

Two of these subjects were in the control group and the other two were

in the experimental group. Thus, skin temperature and percentage of

correct detections data for four subjects, the two from each group that

had no skin resistance data, had to be omitted from the multiple cor-

relation analysis.

An $\underline{F}$ test as described in Ostle (1969) was utilized to determine

the significance of the $\underline{R}$ value obtained. The multiple correlation

analysis provided a value $\underline{R} = 0.6833$ with $\underline{F}(2,13) = 5.6943$ and

$\underline{p} < 0.025$ for the experimental group. The multiple correlation

coefficients obtained for the control and combined groups were not

significant.

As can be seen in Appendix A, the number of commissive errors

committed by the subjects was small and no significant analyses could

be made of this data.

2.   Skin Temperature

Table II shows the results obtained from a two way nested

analysis of variance on skin temperature (°C).

Table II.   Analysis of variance on skin temperature (°C)

Source	df	SS	MS	F	p
Between Subjects	11	494.21			
Audio Stimulus	1	232.41	232.410	8.877	0.025
Error (bet.)	10	261.80	26.180		
Within Subjects	36	5.23			
Time Period	3	1.14	0.380	3.725	0.025
Time x Stimulus	3	1.02	0.340	3.333	0.050
Error (with.)	30	3.07	0.102		
Total	47	499.44			

From Table II it can be seen that the differences due to the application of the external audio stimulus, the four time periods, and the Time x Stimulus interaction were all significant at the indicated levels.

A simple linear correlation analysis was performed with skin temperature as the independent variable and the transformed percentage of correct detections as the dependent variable. These two correlations were calculated for the control group, the experimental group, and the two groups combined. A two-tailed t test was utilized to check the significance of the r value obtained.

The experimental group was found to have a linear correlation coefficient, $r = -0.6499$ with $t_{(22)} = -4.01089$ and $p < 0.001$. For the combined group the linear correlation coefficient between the transformed percentage of correct detections and skin temperature was

$r = -0.2283$ with $t\ (46) = -1.59032$ and $p < 0.13$. The linear cor-
relation coefficient for the control group was not significant.

　　3.　Skin Resistance

　　　　It was stated in the SEQUENCE OF EVENTS that skin resist-
ance was calibrated after each subject had been tested. During the
calibration, it was found that the level of skin resistance for four of
the subjects was higher than the range of the decade resistor used for
calibration. Fortunately, for the purposes of analysis, two of the sub-
jects were in the control group and the other two were in the experimental
group. Thus, it can be seen in Table III that the degrees of freedom
for the analysis of variance on skin resistance are different than those
in Tables I and II. This difference is due to the fact that only eight
subjects were utilized in the two way nested analysis of variance.

Table III.　Analysis of variance on skin resistance (K-OHMS)

Source	df	SS	MS	F	p
Between Subjects	7	1,514,971			
Audio Stimulus	1	513,731	513,731	3.078	N.S.
Error (bet.)	6	1,001,240	166,873		
Within Subjects	24	358,939			
Time Period	3	316,805	105,602	50.551	0.0005
Time x Stimulus	3	4,525	1,508	0.722	N.S.
Error (with.)	18	37,609	2,089		
Total	31	1,873,910			

As Table III shows, the only significant F value obtained was for the changes in skin resistance during the four time periods with the high probability shown.

A simple linear correlation analysis was performed with skin resistance as the independent variable and the transformed percentage of correct detections as the dependent variable. These two correlations were calculated for the control group, the experimental group, and the two groups combined. None of the linear correlation coefficients computed proved to be significant.

C.   DISCUSSION

In the instructions, the subjects were required to remain seated in a comfortable position throughout the vigilance task. Nothing was said about talking, singing, or minor movements of the body and limbs. The actions of five of the subjects, two from the control group and three from the experimental group, warrant mention. One subject called out the names of cities, the names of states, and sang, in an apparent random order throughout most of the vigilance task. Another subject stamped his feet for five minutes during the second time interval, and then hummed, sang, and jabbered incoherently and intermittently during the remainder of the vigilance task. A third subject yawned often and audibly after the first time interval. One subject uttered interrogatory statements with decreasing frequency throughout the first two time intervals, since the statements were not answered; and another subject exhibited the fidgets and squinted throughout the last three time

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intervals. The remaining seven subjects made no audio sounds and sat in a relatively fixed position throughout the entire vigilance task. The actions of the five subjects described above are in support of the Arousal Theory; for in effect they were actually adding to the level of arousal stimulus themselves and thereby increasing cortical activity.

VI. CONCLUSIONS

The application of the external audio signal did not have a significant effect on the mean number of correct detections throughout the vigilance task. However, as can be seen in Figure 1, and shown in Table I, there is a significant difference in the interaction between the time intervals and the audio signal. It appears that the application of the audio signal might be beneficial during a vigilance task of a longer duration.

It is felt that the data shown in Appendix A requires that the differences in skin temperature between the control and experimental groups be attributed primarily to the basic individual temperature differences exhibited by the subjects, and not due to the audio signal. That is, since the subjects were randomly assigned to the two groups, if the subjects in the control group had instead been assigned to the experimental group, then the skin temperatures of the control group would have been significantly higher vice the results shown in Figure 2.

As a result of the preceding conclusion, and the lack of a significant difference in skin resistance due to the application of the external audio stimulus as shown in Table III, it must be concluded that the introduction of the external audio stimulus did not produce any significant changes in the physiological parameters that were measured.

The significant negative linear correlation coefficient found between skin temperature and the number of detections for the

experimental group is contrary to both the results obtained by Tinsley (1969) and the intuitively expected positive correlation. No explanation can be stated for this phenomenon since this correlation is a measure of the change in skin temperature within each subject during the vigilance task, and not due to the different basic individual temperature readings.

The control and experimental groups were analyzed separately in the linear and multiple correlation analyses. This was done to see if there was a greater trend for one of the groups towards significant correlation than the other. There was no significant difference between the two groups in this respect.

Since there was a significant difference in the skin temperatures of the control and experimental groups, but no significant difference in the mean number of detections throughout the vigilance task between these groups, skin temperature alone cannot be considered as a measure of detection performance. However, the significant multiple correlation coefficient with percentage of correct detections as the dependent variable implies that it would be beneficial in future research to increase the number of physiological parameters measured to try to find a complex index of physiological parameters that is related to vigilance detection performance.

APPENDIX A.   SUMMARY OF OBSERVED DATA

Parameter	Subject	Time Intervals			
		I	II	III	IV
Transformed	1	2.094	1.047	1.824	1.047
Percentage	2	3.141	1.824	2.419	2.419
of	3	2.419	2.094	2.094	2.094
Signals	4	2.094	1.047	1.824	1.824
Detected	5	3.141	2.419	3.141	3.141
	6	1.571	2.419	1.571	0.7226
	7	2.094	2.094	1.824	2.094
	8	1.318	1.047	1.047	1.318
	9	3.141	2.419	1.824	3.141
	10	2.419	1.824	2.094	3.141
	11	2.419	1.318	1.824	2.094
	12	2.419	2.094	1.318	2.419
Number	1	0	0	0	0
of	2	1	0	0	0
Commissive	3	0	0	0	0
Errors	4	4	0	2	1
	5	0	0	0	0
	6	1	0	0	0
	7	0	0	0	0
	8	0	1	0	0
	9	0	0	0	0
	10	0	0	0	0
	11	1	0	0	3
	12	0	0	0	0
Skin	1	29.90	29.60	29.40	28.55
Temperature	2	25.01	25.21	24.90	24.62
($^\circ$C)	3	31.59	31.37	31.01	30.75
	4	23.68	23.61	23.55	23.43
	5	27.03	26.69	26.28	25.95
	6	26.70	26.15	26.01	26.15
	7	31.54	31.72	32.18	31.52
	8	33.12	33.66	33.62	33.53
	9	28.54	27.86	28.40	29.27
	10	28.97	29.20	28.83	28.16
	11	33.57	34.26	33.87	33.50
	12	31.77	32.21	31.95	31.51

| | | Time | Intervals | | |
Parameter	Subject	I	II	III	IV
Skin	1	1,146.53	1,000.00	923.10	848.10
Resistance	2	417.50	317.50	265.00	231.00
(k-ohms)	3	907.50	715.00	592.08	500.00
	4	862.50	714.92	637.50	570.00
	5	713.12	525.00	433.75	385.00
	6	373.95	375.83	336.83	295.42
	7	582.17	502.08	412.50	320.00
	8	488.00	368.92	271.00	210.11

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DOCUMENT CONTROL DATA - R & D

Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY (Corporate author)	2a. REPORT SECURITY CLASSIFICATION
Naval Postgraduate School	
	2b. GROUP
Monterey, California 93940	

3. REPORT TITLE

The Effect of an External Audio Signal on Vigilance Performance and Physiological Parameters

4 DESCRIPTIVE NOTES (Type of report and inclusive dates)

Master's Thesis; March 1970

5 AUTHOR(S) (First name, middle initial, last name)

William Stanley Marshall III

6 REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
March 1970	45	15
8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)	
b. PROJECT NO		
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
d.		

10 DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution
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11 SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
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13 ABSTRACT

This research was performed to determine the effect of an external audio signal on visual monitoring performance and any associated changes in physiological parameters of the subjects. The number of correct detections, the number of commissive errors, skin temperature, and skin resistance were recorded throughout the experiment. A two way nested analysis of variance showed that the application of the audio signal did not have a significant effect on the vigilance decrement. The same type of analysis was used to show that the audio signal did not have a significant effect on the physiological parameters measured in the experimental group. Over all experimental groups, skin resistance and skin temperature did change, but the changes were not unique to any given experimental condition. Multiple correlation analyses of the data indicated a high degree of complex interaction between the physiological parameters measured and the vigilance detection decrement.

D FORM 1473 (PAGE 1)
1 NOV 65

N 0101-807-6811

47

A-31408

14 KEY WORDS	LINK A		LINK B		LIN
	ROLE	WT	ROLE	WT	ROLE
Vigilance Performance					
Physiological Parameters					
External Audio Signal					
Detection Performance					